THE EFFECT OF ILLUMINATION AND STAGE OF TIDE ON THE ATTACHMENT OF BARNACLE CYPRIDS*

CHARLES M. WEISS

Woods Hole Oceanographic Institution, Woods Hole, Mass.

The attachment of barnacle cyprids to exposed surfaces is influenced by the degree of illumination and the surface color. Cyprids of *Balanus amphitrite* and *Balanus improvisus* were found by Visscher (1927) to attach in greater numbers to dark or shadowed surfaces. McDougall (1943) noted this same behavior for the cyprids of *B. eburneus*. When exposed only at night, however, Pomerat and Reiner (1942) noted that *B. eburneus* attached to black, clear and opal glass in equal numbers. Twice as many barnacles attached to the black glass in natural day-night exposures. Gregg (1945) investigated the effect of contrasting dark surfaces against lighter general surroundings. He concluded that while no correlation could be established between the degree of contrast and the frequency of attachment, "shading" was suggested as acting as a stimulus to the attachment of the larvae of *B. eburneus* to opal glass collectors.

In the present investigation the rate of attachment of cyprids of *B. improvisus* during daylight and night exposures, and the effect of artificially illuminating the collecting surface at night were observed. The effect of the tide on the rate of attachment of cyprids was also studied. This work was carried out at the boat shed of the Beach Boat Slips Corporation in Biscayne Bay, Miami Beach, Florida.

Methods

Four stations for sampling the barnacle cyprid population were established under and adjacent to a covered boat slip which extended 250 feet from the shore, the stations being at the outer end of the shed.

Stations A, B and C were control stations for comparison with Station D, which was illuminated at night. Stations A, D and B were spaced 55 feet apart, in that order in a north-south line paralleling the general flood and ebb movement of the tidal current. Station C was located 60 feet to the west of Station D. The conditions of natural and artificial illumination at each of these stations were as follows: In the daylight hours illumination at each of the four stations was nearly the same through the day. The intensity at each location depended on the proximity of the shadow of the shed. At Station A, daylight illumination was skylight; at Station B, the collector swung in and out of the sun and shadow of the shed with the phase

* Contribution No. 400 from the Woods Hole Oceanographic Institution. The observations were made during an investigation by the Woods Hole Oceanographic Institution under contract with the Bureau of Ships, Navy Department, which has given permission for their publication. The opinions presented here are those of the author and do not necessarily reflect the official opinion of the Navy Department or naval service at large. The author is indebted to Dr. B. H. Ketchum, Dr. L. W. Hutchins and Dr. A. C. Redfield for helpful advice and criticism and to Mr. Alexander C. Frue for assistance in making the observations.

of the tide; and Station C was in full sunlight, whereas Station D was under the shed roof and in the full shadow. At night, Station D was artificially illuminated, while Stations A, B and C were in darkness.

Collecting units consisting of four pieces of black glass (500 sq. cm. collecting area) were suspended from a float. The surface panel was horizontal while the others, at depths of 2, 6 and 10 feet, were hung in a vertical position. The 10-foot level was just above the bottom at low tide and three feet higher at high tide.

The periods of collection, day and night, were eleven hours each, from 7:30 A.M.–6:30 P.M., and 7:30 P.M.–6:30 A.M. The eleven-hour exposure permitted no significant overlapping period of dark to light or light to dark when the collectors were in the sea. The one-hour interval between exposures permitted counting, cleaning and reimmersing of the collection units.

Table I

Numbers of cyprids attaching during consecutive night and day periods of eleven hours each at three stations. The figures are the sum of the collections on four panels of 500 sq. cm. area each, hung at different depths.

Cyprid attachment night			Cyprid attachment day			Average	
Stations			Stations			Night	Day
A	B	C	A	B	C		
*394	205	306	403	614	784	302	600
418	279	272	386	897	997	323	760
463	534	778	1361	1392	2018	592	1590
434	768	497	701	666	1147	566	838
296	160	483			.	313	
**444	533	432	2352	1149	3564	470	2355
391	446	541	636	569	1829	459	1011
255	201	479	432	881	1092	312	802
219	168	240	676	564	1581	209	940
114	99	101				105	

* February 11, 1946–February 16, 1946. ** February 26, 1946–March 3, 1946.

Although the source of illumination at Station D remained fixed while the collector unit which hung below it rose and fell with the tide, an average distance of 5 feet from the lights to the water surface was used in calculating the value of incident illumination at the water surface and at the 10-foot depth. The incident illumination five feet from the lights was measured by a direct reading photometer and that at the 10-foot level calculated by using an absorption factor for the local waters determined with an underwater photometer.

The study of cyprid attachment relative to stage and direction of the tide was made by counting the cyprids attaching during intervals of two hours throughout a tidal cycle in daylight hours only. The collecting units were the same as those employed in the illumination experiments.

Diurnal Variation in Cyprid Attachment

Observations on five successive nights and four intervening days in two separate series indicated that many more cyprids settled during the period of daylight, as shown in Table I. In the first set of observations, the ratio of the average of all the day collections to the average of the corresponding night collections indicated an increase of 2.1 times the number of cyprids attaching in daylight, while in the second series the ratio of day to night attachments was 3.5.

It is of interest to note that in the first set of collections when the cyprid density, as shown by total attachment day and night, was lower than the second set of collections there are examples of day collections being nearly of the same magnitude or even slightly less than the night attachments. This condition was found only at Stations A and B which were wholly or partially shaded from direct sunlight during the daylight hours. A partial explanation of the relatively high night attachments of the first set of collections may be due to the fact that these were made under the full of the moon whereas the second set were made in the dark of the moon. However, when the cyprid density was high, as during the second set of observations, no discrepancies from the diurnal fluctuation in attachment were noted. The maximum differences between night and day attachments were always found at Station C which had the maximum difference in illumination.

Vertical Distribution of Cyprid Attachment

The vertical distribution of barnacle cyprids at Stations A, B and C showed no consistent pattern which would suggest dependence on any particular controlling factor. In the first set of collections, shown in Figure 1, the maximum numbers at Station A, both day and night, were found at the 2-foot level. At Station B, all the day collections showed cyprid peaks at the 6-foot level, whereas, at night, attachment was nearly uniform between the 2-foot level and the bottom, except for one observation. At Station C, the day collections resulted in maxima at the 2-foot level on three occasions and a 6-foot maximum on one occasion.

The second series of vertical samplings, as shown in Figure 2, were made at a period of higher cyprid density which resulted in collections of considerable magnitude for several of the eleven-hour periods. However, no consistent pattern of vertical distribution was apparent.

This erratic distribution of cyprids, both vertically and in comparison of stations, is of particular interest, in view of the relatively close proximity of the collecting units. The apparent random attachment of cyprids to the collecting units is probably due to a nonuniform distribution of cyprids in the water. Since the number of cyprids attaching does not decrease with depth, it is apparent that intensity of illumination does not control vertical distribution.

Effect of Artificial Illumination on Cyprid Attachment

The normal diurnal cycle, with lower attachment numbers at night, was abolished by the use of artificial illumination at night at Station D. The cyprid attachments at night under artificial illumination at Station D were greater than the daylight counts at this location and were nearly as large as the daytime collections at Station C where the intensity of daylight illumination was greatest. As shown in

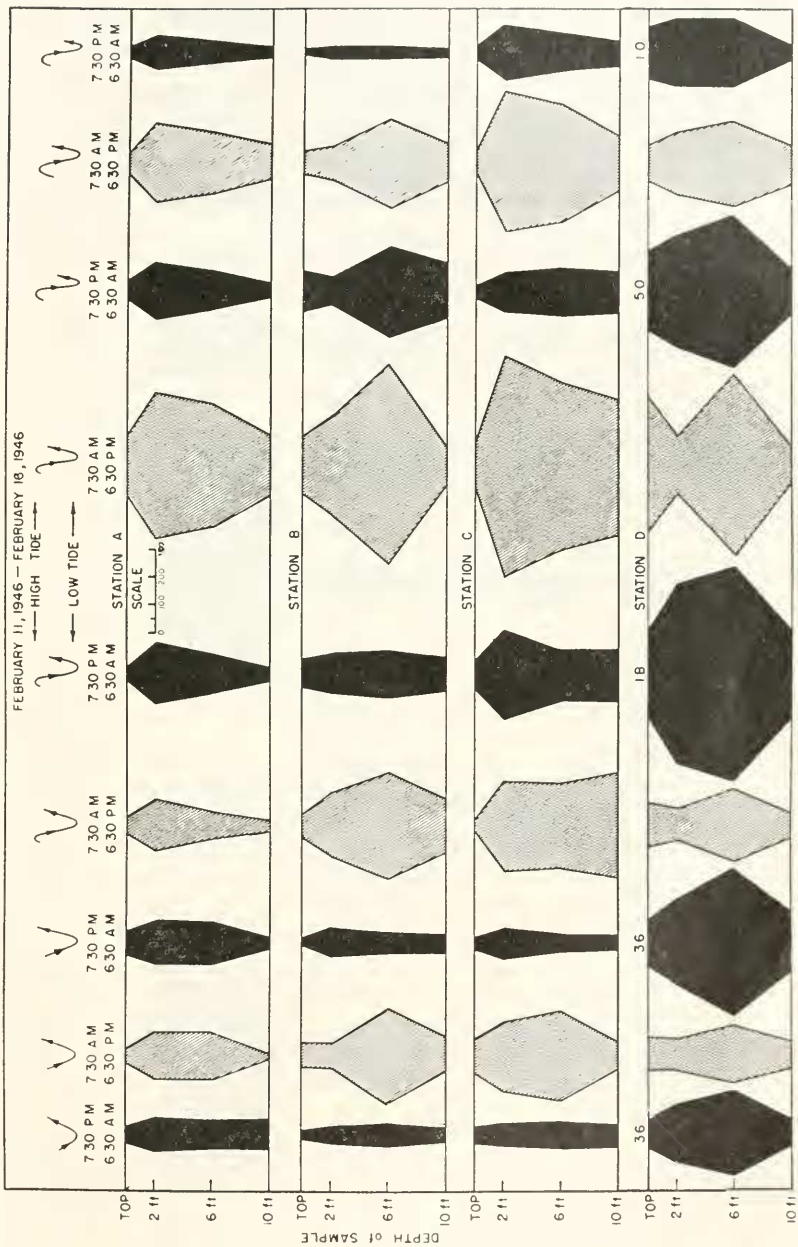

FIGURE 1. Vertical distribution of cyprids at four stations as collected in eleven-hour periods, February 11, 1946–February 16, 1946. The tidal curves at the top of the figure represent the stages of the tide in which the collection took place. The numbers over the night collections of Station D are the illumination values in footcandles at the water surface used for that exposure.

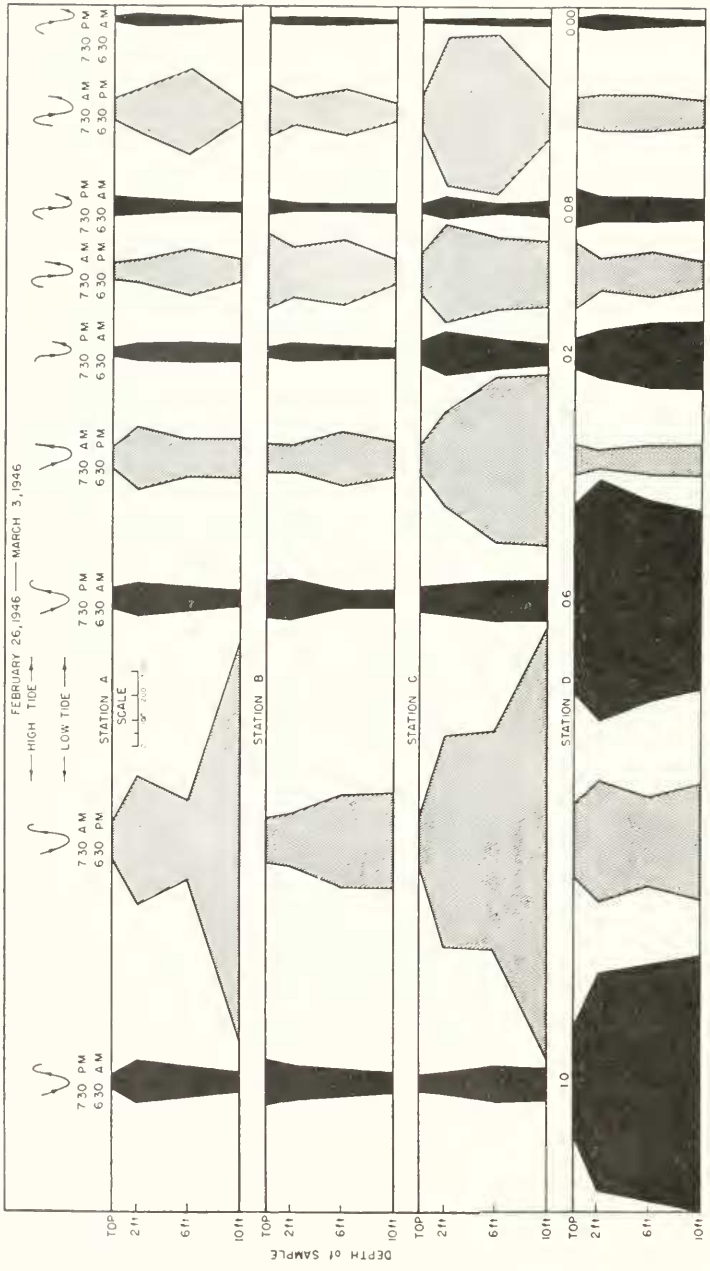

FIGURE 2. Vertical distribution of cyprids at four stations as collected in eleven-hour periods, February 26, 1946–March 3, 1946. The tidal curves at the top of the figure represent the stages of the tide in which the collection took place. The numbers over the night collections of Station D are the illumination values in footcandles at the water surface used for that exposure.

Figures 1 and 2, artificial illumination, however, had little if any effect on vertical distribution of the cyprids.

In order to determine the intensity of illumination necessary to increase the cyprid attachments at night, the illumination over the collectors at Station D was

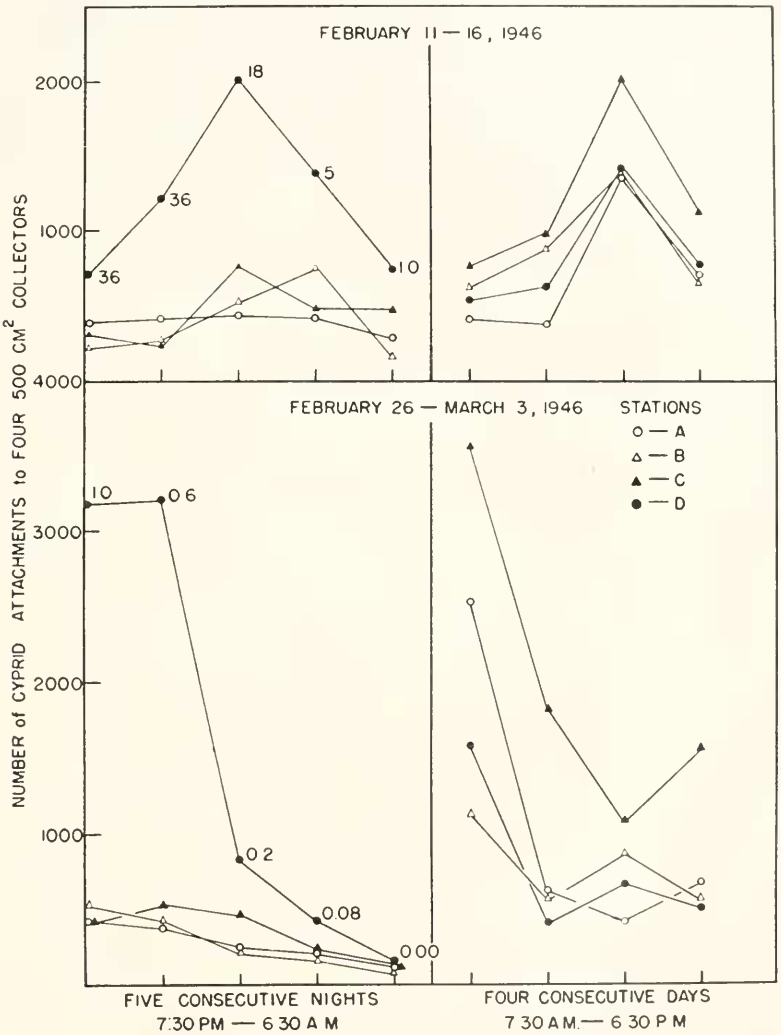

FIGURE 3. Total cyprid attachment for the eleven-hour collection periods at each station. The numbers plotted with Station D, night collections, are the values in footcandles at the water surface of the artificial illumination employed.

systematically changed. In the first series, the incident illumination at the water surface was varied from 36–1.0 footcandles, and in the second experiment, from 1.0–0.00 footcandles. The variations in vertical distribution at each station, which are apparently due to other factors, have been smoothed by totaling the cyprid accu-

mulations from each of the four glass collectors. This figure then represents the catch from the cyprid population of a vertical column of water. As shown in Figure 3, the illumination of the collectors at Station D resulted in a two to sevenfold increase in numbers of cyprids attaching over those found on the control surfaces. The daily variation in cyprid numbers attaching at night to the illuminated collectors of Station D resembled more nearly the daily fluctuation in cyprid density as found on the daylight collections of Station C. Although the night collections of Station D paralleled the cyprid density fluctuations as found at the unilluminated stations, they were of course several times greater in magnitude. This result was obtained within the limits of illumination of 36 to .08 footcandles at the water surface. On the final night exposure of the second series, when Station D was not illuminated, its cyprid collection was still slightly greater than the other three stations. However, this difference is probably within the normal variation. During the day the collections at Station D were of the same magnitude as at A and B and considerably less than those at C.

TABLE II

Numbers of cyprids attaching in eleven hours at night at the 10-foot depth at Station D as related to quantity of artificial illumination and in comparison with the simultaneous attachment at Stations A, B and C.

Value of illumination at D at 10-foot depth (footcandles)	Stations				D / 1/3(A+B+C)
	A	B	C	D	
*5.2	110	45	87	102	1.3
5.2	38	71	56	219	4.0
2.5	45	117	184	318	2.8
.71	42	206	136	169	1.3
.14	44	34	90	64	1.1
** .14	78	92	135	1005	9.9
.09	59	71	158	710	7.4
.03	65	37	81	257	4.2
.001	38	44	66	77	1.6
.000	7	15	33	21	1.1

* Five consecutive nights—February 11, 1946–February 16, 1946.
** Five consecutive nights—February 26, 1946–March 3, 1946.

The artificial illumination, even at the 10-foot depth, consistently increased the number of cyprids attaching to the collecting surface of Station D in comparison with the control stations, as shown in Table II. The ratio of the attachment at Station D to the averages of Stations A, B and C indicates the degree of change in attachment due to illumination. The greatest differences between the illuminated collectors and controls occurred on the second and third nights of the first experiment when cyprid attachment was at a maximum. In the second set of exposures, when cyprid density was high, all the collections at the 10-foot level of Station D, even though the illumination was very low, were invariably greater than all the controls.

As indicated above, the illumination of the water surrounding the collectors was varied systematically to determine the minimum value to which the cyprid would

respond. When the cyprid density was high, thus providing more organisms which would by random selection be subjected to the contrast of luminous zone and dark area, the greatest change in cyprid attachment occurred when the illumination of the water surface was changed from 0.6 to 0.2 footcandle. At 0.6 footcandle and greater intensities, the difference in cyprid settling, in comparison to the controls, was sevenfold, while at 0.2 footcandle and less, the increase over the control col-

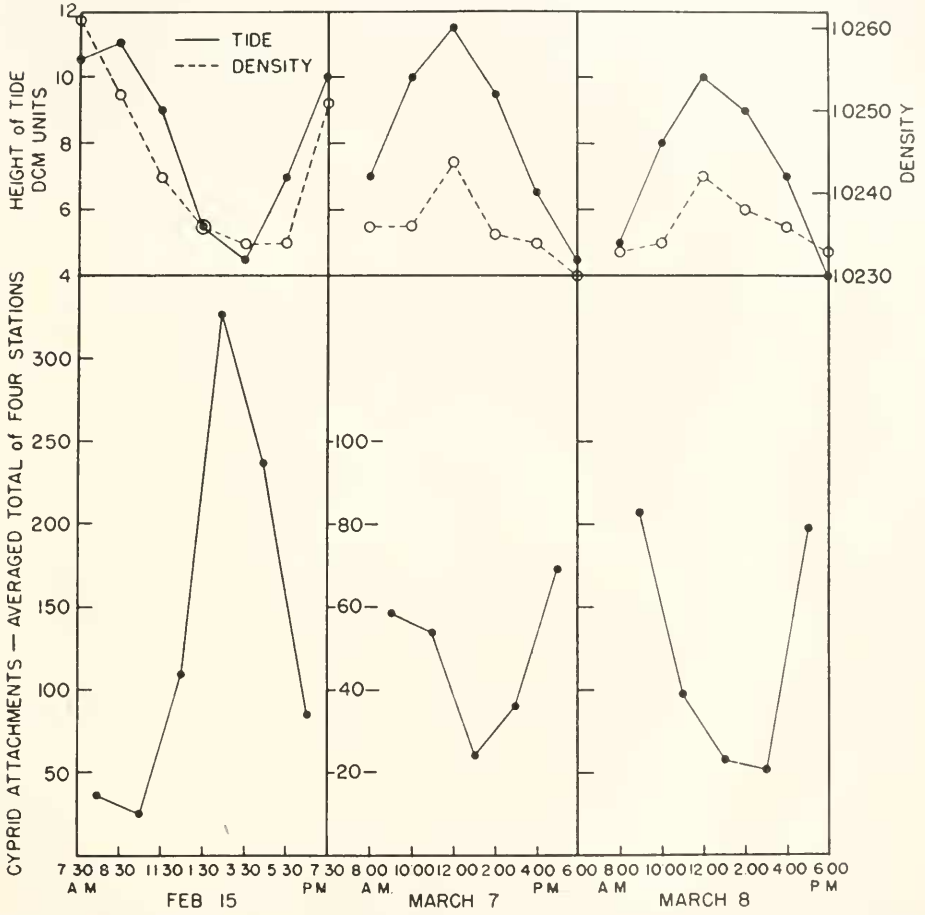

FIGURE 4. Bi-hourly cyprid attachment at each station totaled from the four collecting surfaces. The height of tide is noted in decimeter units. February 15, March 7 and 8, 1946.

lectors was only twofold. However, at illumination as low as .03 footcandle, increases in attachment over control collectors were still considerable.

Previous investigations (Visscher, 1927; Pomerat and Reiner, 1942; and McDougall, 1943) showed that the barnacle cyprid attaches in daylight in greater numbers to dark surfaces than to light surfaces. At night, as is to be expected, there is no distinction between the two colors. In this investigation illumination of dark collecting surfaces at night increased attachment. One effect of illumination

is to increase the contrast between the dark surfaces and the surrounding water. In waters with considerable suspended material, as usually found in harbors and estuaries, a beam of light is markedly scattered, producing a general illumination in the water. A piece of black glass suspended in these waters under a source of illumination was discernible to the observer as a black area surrounded by brighter water. When the water appears brighter than the collecting surface, at night because of artificial illumination, or during daylight, the cyprids may be attracted to the darker area by some negative phototropic response and may accumulate there in greater numbers than would result from chance encounters. In contrast, in the absence of light at night, the numbers of cyprids attaching may depend solely on chance encounters with the collecting surface, and are consequently lower than during periods of illumination.

Effect of Stage of Tide

On collectors exposed through the day and examined at two-hour intervals, the maximum numbers of cyprids attached during the low-tide period as shown in Figure 4. This was found whether the low tide occurred at midday, in the early morning, or late afternoon. As in the case of the longer exposures, there was no indication that the distribution of cyprids on the panels was influenced by the depth at which they were hung.

At the location of this experiment, the ebbing tide brings to the boatshed water which is isolated within the bay. It is replaced at high tide with oceanic water entering the bay on the flood. This is shown by the change in density accompanying the tidal cycle. The isolation of the bay water permits development of a large cyprid population, since few of the plankton stages are lost into the ocean prior to metamorphosis to the cyprid stage. At the low-tide period, the sampling location was occupied by the bay water with high cyprid content, and this apparently accounts for the greater attachment at that time. The high attachment at low tide cannot depend upon the lessened flow at that time, since a similar slack water occurs at high tide when the attachment is minimal.

Summary

1. The cyprid larvae of *Balanus improvisus* were found to settle in a diurnal rhythm with maximum numbers attaching during daylight hours.

2. No consistent pattern of vertical distribution of the cyprids was found.

3. The normal diurnal cycle in rate of attachment of barnacle cyprids was nullified by the use of artificial illumination over the collecting surfaces at night.

4. The magnitude of the cyprid collection on the artificially illuminated surfaces was equal to the collection on the sun-illuminated surfaces in daylight.

5. The intensity of artificial light necessary to produce large cyprid attachments at night was of an order as low as 1 footcandle at the water surface.

6. No correlation was found between the quantity of artificial light at night and the numbers of cyprids attached.

7. The highest rate of cyprid attachment relative to the phase of the tide was found to occur when the waters of upper Biscayne Bay were sampled at the collecting station. This body of water reached the sampling station at low tide and was characterized by a high cyprid population.

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